A STUDY OF THE RELATIONSHIP OF THE PERCENT OF FULL SUNLIGHT WITH COMMUNITY SYNECOLOGICAL LIGHT VALUES

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The relationship of plants to their light environment has been investigated by numerous people interested in forestry and biological sciences. Light is an important environmental component and is particularly important in forestry practices.

This paper will report the results of research carried out in the summer of 1966 at Itasca State Park in northwestern Minnesota. The objectives of this research were threefold:

1. To determine the percent of full sunlight (both direct and diffuse) above brush (below mature, well stocked, forest tree canopies, below brush (below the understory and brush canopies), and at ground level (below the herbaceous canopies) for four forest cover types.
2. To determine the variation of light intensity within four different forest cover types.
3. To compare the community synecological light values, as derived by the method described by Bakuzis and Hansen (1959), with percent of full sunlight above the brush, below the brush, and at the ground level.

LITERATURE REVIEW

Light is usually defined as that portion of the short-wave radiation of the sun which is visible to the human eye. This light is more technically called visible light and makes up about 40 percent of the solar energy received on the earth's surface. Visible light has a range of wavelengths from 400 to 700 millimicrons. The visible light color spectrum is violet .40 to .45 micron, blue .45 to .50 micron, green .50 to .57 micron, yellow .57 to .59 micron, orange .59 to .61 micron, and red .61 to .70 micron(Daubenmire, 1959, and Reifsnyder and Lull, 1965).

About 10% of the solar energy is in the ultraviolet region of 100 to 400 millimicrons, and the remainder of the solar energy is in the infrared region of 700 to 2000 millimicrons (Reifsnyder and Lull, 1965).

Reifsnyder and Lull (1965) list the photochemical effects of specific wavelength bands according to the Dutch Committee on Plant Irradiation:

Band 1. Greater than 1 micron. No specific effects of this radiation are known; as far as it is absorbed by the plant it is transformed into heat without interference of biochemical processes.

Band 2. 0.7 to 1 micron. The region of specific enlongating effect on plants.

Band 3. 0.61 to 0.7 micron. Strongest absorption of chlorophyll and strongest photosynthetic activity. In many cases the region of strongest photoperiodic activity.

Band 4. 0.51 to 0.61 micron. Lowest photosynthetic effectiveness.

Band 5. 0.4 to 0.51 micron. Strong chlorophyll absorption and absorption by yellow pigments, and strong photosynthetic activity in the blue-violet.

Band 6. 0.315 to 0.4 micron. Fluorescence and strong photographic action.

Band 7. 0.28 to 0.315 micron. Antirachitic and germicidal action.

Band 8. Less than 0.28 micron. Below the atmospheric transmittance limit for sunshine.

A foot-candle is one unit used in illumination measurements, and is defined as the illumination on a uniform surface which is one square foot in area, and is everywhere one foot from a standard point source of light with one candle of intensity (Shirley, 1931). Another unit to express illumination is called the "daylight factor" which is the ratio of the amount of diffuse light in a forest to the diffuse light in the open (Evans, 1956). Anderson (1964) introduced the term "site factor" which can be used, instead of percent reduction of light, to describe any ratio of light intensities as long as an appropriate qualification as to the type of light and time of measurement is given. "The 'total site factor' is the percentage of total (diffuse plus direct) light at a given site compared with total light in the open over the same period." (Anderson, 1964).

"Light is one of the most important factors in the growth of plants and also one of the most difficult to study." (Shirley, 1935). The basic problem in light studies is the variations which occur in light intensity and light quality in a forested area and even in an open area.

Light intensity at a particular spot on the earth's surface is dependent on the geometry of the earth's orbit and the particular orientation of the spot under consideration (Fairbairn, 1954; Reifsnyder and Lull, 1965; and Shirley 1935). The components important in the geometry of the earth's orbit include distance of the earth from the sun, latitude or angle at which the solar stream strikes the earth, declination or tilt of the earth on its axis which is responsible for the seasons, and the conditions of the earth's atmosphere. The earth's atmosphere changes the intensity and also the quality of the solar stream depending on the mass of atmosphere that is traversed, turbidity caused by atmospheric particles, and cloudiness (Reifsnyder and Lull, 1965). Shirley (1945) stated that he believed that atmospheric humidity and cloudiness are among the important factors causing variations in light intensity. The light intensity is also greatly effected by the orientation or local obstructions at the spot, this would include the slope and aspect, surrounding topographic features and vegetation, and the elevation. The amount of cloudiness and slope and aspect are important in light intensity in another manner, that is, the relative portions of direct and diffuse light incident on the earth's surface (Reifsnyder and Lull, 1965). A steep slope with a north aspect, for example, will have a greater percentage of diffuse light and lower light intensity than a steep south slope (Fairbairn, 1954). On a cloudy day diffuse radiation accounts for large amounts of solar radiation, hence on cloudy days a steep north slope receives more light than on a clear day (Reifsnyder and Lull, 1965).

Light quality is also affected by the atmospheric conditions and surrounding obstructions. According to Reifsnyder and Lull (1965) the atmosphere absorbs nearly all the ultraviolet, especially from 0.1 to 0.315 micron (bands 7 and 8), and nearly half of the infrared, greater than 1 micron (band 1).

Surrounding obstructions have an effect on light quality also, but it is very small compared to that of the atmosphere. Geiger (1966) in reviewing work done in several European studies, states that there is a preponderance of red wavelengths in the internal radiation of the forest. The leaves of forest trees and vegetation modify the light quality making it richer in the red wavelengths (0.61 to 0.71 micron). For comparison, the shade under a wooden shelter receives mainly blue or diffused light from the sky (0.40 to 0.50 micron) (Reifsnyder and Lull, 1965). Leaves tend to increase the amount of green light in a forest by absorbing the blue and red wavelengths. The effect of the change in light quality on plants will be described later. The wavelengths of maximum absorption are also the wavelengths of minimum reflection and scattering. Hence, the yellow and green wavelengths tend to be reflected and scattered more strongly then the blue or red wavelengths (Czarnowski and Slomka, 1959; and Gates and Tantroporn, 1952).

Light available to plants beneath a forest canopy is of a lower intensity than that in the open. According to Park (1931) in work in the Chicago area, light in the open is about 1000 foot-candles in the winter and climbs steadily to 10,000 foot-candles in late summer, after which it falls steadily again. Deciduous forests have a different intensity pattern than do open areas, since in late summer, which is the peak of intensity in the open, the branches of trees are heavy with foliage, and hence there is a minimum of light on the forest floor. The maximum light intensity comes in the spring and fall periods. Park (1931) reports a range of light intensities from 400 to 4000 foot-candles in pioneer cottonwood forests and from 40 to 2500 foot-candles in climax maple forests. Ovington and Madgwick (1955) report 30 to 60 percent light penetration in early spring, but greatly varying amounts in the summer because as the full sunlight value increases, the absolute quantity of light increases, but the percentage penetrating decreases. Coniferous forests have a quite constant light environment despite the accumulation of snow on the branches in the winter which lowers the light intensity, and the greater reflection and absorption in the summer months due to the presence of new and old needles (Ovington and Madgwick, 1955; and Park, 1931). Park (1931) reports a range for coniferous stands, in the Chicago area, of 500 to 800 foot-candles, and Ovington and Madgwick (1955) report 0.5 to 6.7% intensity in English conifer forests.

A forest will receive both diffuse (skylight) and direct light. The direct light will be in the form of sunflecks (Shirley, 1935). Daubenmire (1959) reports wind blown leaves cause rapid movement of sunflecks and shadows across the ground which results in a rapid and wide variation from about 2% in the shade to 35% in a sunfleck, then back again to 2% after only several moments to a few minutes. Shirley (1935) also reports 30 to 40% intensity in sunflecks. Evans (1956) reported on sunfleck work in the forests in Nigeria. He states that, considering clouds and the middle of the day sunfleck period, about 70% of the total energy on the forest floor would be sunflecks in the period from January to March. Sunflecks will occur for a shorter period in the temperate region and will be less important. To date no measurement of energy supplied by sunflecks has been done for the temperate region.

Light intensity is important to tree growth, but many other factors are interrelated with light and are also important. Pearson (1930) working in western yellow pine and Strothmann (1967) working in red pine in Minnesota discovered that light intensities were more critical to seedling growth than was soil moisture once the seedlings were established.

Light intensity is important in plant growth under a forest canopy. Shirley (1929,b) reports that dry weight matter production by plants was nearly directly proportional to the light intensities, up to 20% of the full sunlight value, thereafter the rate of increase was more gradual. The light intensity under fully stocked forest stands is always below the optimum for growth, which is usually higher than 20%. Shirley (1945) and Roussel (1948 as reported in Reifsnyder and Lull, 1965) report that the lower limit for herbaceous growth is 4% intensity (mosses can occur in 1-3% light intensity). Buell and Gordon (1945) report that in studying the conifer-hardwood forest contact zone in Itasca State Park, "A somewhat abrupt increase in the number of plants after light penetration exceeds 5 percent, suggests that the limiting point for ground cover is near this value." Atkins (1957) states that a minimum of 25% of full sunlight intensity is needed for satisfactory white pine seedling growth.

Plants and tree seedlings can survive under low light intensities. Red and white pine, chestnut and red oak, and hemlock seedlings survived 10 months with less than 300 foot-candles of light. The compensation point was 170 foot-candles, and another 170 foot-candles maintained ample growth (Grasovsky, 1929). Shirley (1929,b), in a study of oaks, loblolly pine, redwoods, and some herbs, reports that they could survive 3 to 6 months with 1% light intensity, but could not increase their dry weight.

Shirley (1929,a) lists the effects of dense shade and low light intensity on plant growth. Herbs and tree seedlings tend to increase height growth at the expense of diameter growth, top growth at the expense of root growth, leaf area at the expense of leaf thickness, and succulence at the expense of strength and sturdiness. Daubenmire (1959) stated that light intensity which is too high may cause physiological damage and excessive transpiration.

Light quality is changed considerably as it passes through a forest canopy yet it appears to have sufficient percentages of the various wavelengths to induce normal growth (Shirley, 1929 a,b; Daubenmire, 1959; and Grasovsky, 1929). Plants grew better in light without the red portion of the spectrum than they did in light without the blue portion of the spectrum. The complete light spectrum induced the best growth (Shirley, 1929a).

The leaves of a green canopy tend to transmit 10% more green than blue, and 15% more green than red. Leaves absorb more blue than red and more red than green (Shirley, 1945). When equal amounts of energy in the various wavelengths are absorbed by a leaf, the green wavelengths are found to be between the blue and red wavelengths in photosynthetic efficiency (Shirley, 1935).

Coombe (1957) and Czarnowski and Slomka (1959) report that deciduous canopies are more selective filters of light than are coniferous canopies. A *Castanea* forest was found to be nearly equal to a *Picea* forest in its effect on the color spectrum, except in the red wavelengths, which were much more abundant in the *Castanea* forest(Coombe, 1957).

"All plant species have certain environmental requirements for moisture, nutrients, light, and heat. For forestry purposes requirements of a species in terms of its essential environmental factors are of primary concern when the species is under the conditions of competition prevailing in the forest." (Bakuzis and Hansen, 1959). A species of forest tree commonly found in full sunlight is believed to have a high light requirement. Before the work of Bakuzis and Hansen (1959) no previous work had been attempted with site factor classification, except for formal classifications of light tolerance.

To establish a uniform scale of moisture, nutrients, light, and heat, previously published information on 32 tree species, 55 shrubs and half shrubs, 18 ferns and fern allies, 5 groups of mosses and lichens, and 68 herbaceous species were reviewed. This information was compiled and the four site factors were put on a scale with relative values of 1 to 5 in increasing order of the apparent requirements of the species for the four factors (Bakuzis and Hansen, 1959). In 1957 reconnaissance of 356 systematically chosen forest communities was made to correct the assigned values for the range of ecological communities in Minnesota. The reconnaissance included the preparation of a species presence list, estimates of percent cover of trees, shrubs, reproduction, and herbs, and a description of the soil profile (Bakuzis, 1959). "Community values were determined as averages of the synecological values assigned to the individual species. The value originally assigned an individual species was then corrected on the basis of the average of the community values of those communities in which the species occurred." (Bakuzis and Hansen, 1959).

Shirley (1931) reports in summary the four basic methods of measuring light intensity. The first method is nonselective in that all wavelengths of light are uniformly measured since the instruments measure the "heating effect" of light. The other methods are selective since their response to various wavelengths varies. The "electrical effect" measures illumination by measuring the current induced on to a thin metal surface by the light waves. "Illumination effect" works by comparing the incident light to a light intensity standard. The "chemical effect" is measuring light intensity by observing or measuring the amount of chemical reaction which has occurred.

The "chemical effect" is usually measured with silver salts or another chemical which will react in the presence of light. Anderson (1964) and Evans and Coombe (1959) report that a special camera which can photograph a whole hemisphere can be used with a grid to estimate the light conditions in the forest for an entire day or longer at a very reasonable cost compared to a series of integrated light measurements.

The photometer, a selective, "electrical effect" instrument, which uses a photo-electric cell is described by Fairbairn (1958). The photometers now available are used widely by photographers and are inexpensive, small, light, easily carried, hand held, and easily operated. There are a number of problems involved in its use including (a) only moderate sensitivity at low light values, (b) geometric, not linear response to light, (c) a filter or diffuser is necessary for more intense light levels, (d) a deterioration called solarization from over-exposure to the sun can occur calling for adjustment, (e) light reflected from clothing can give inaccurate readings, (f) each instrument has a special and distinct spectral response which makes standardization of several instruments difficult, (g) the peak spectral response is usually in the yellow or green wavelengths which are the least absorbed by leaves (Shirley, 1931, 1935, 1945; and Fairbairn, 1954, 1958).

Several authors have written about the sample size necessary for adequate light intensity measurements. Minckler (1961) suggests an average of five instantaneous readings taken at 5 regular intervals throughout a day, give results highly correlated with an integrating light meter at one spot in mixed hardwood sites. Atkin (1957) reports that 20 readings at 40 foot intervals in a uniform, normal density red pine plantation in Canada, gave a reasonable indication of available light intensity. He recommends instantaneous readings be taken only at mid-day on clear, bright days when the control (in the open) reading is within 10% of a set standard. Shirley (1935) states that 20 to 40 direct readings at uniform intervals over 1/10 acre will give an average, accurate to about 5% if a fairly uniform canopy is present. Gatherum (1961) reported on experimental work using 25 readings on 1/20 acre plots, in a moderately dense oak forest, which were receiving varying intensities of harvest cuttings. He found that to attain a reliability within 10% of the mean at the 68% level, 292 readings would be required.

Factors other than light are important in the origin and functions of a forest. The work done by Buell and Gordon (1945) shows that moisture, grazing by wild animals, and glacial activity have been important in setting the pattern of forest communities of Itasca State Park. Spurr (1954) discovered a close relationship between the year of fire occurrence and the age of stands of red pine, aspen, and birch. This shows fire to be an important factor in establishing forests. Lee (1924) pointed out that edaphic factors, particularly soil structure and soil moisture content, and biotic factors, particularly shade tolerance, and shrub competition are important in forest succession in the transitional belt in Itasca State Park.

Grafstrom (1961) did work similar to the work of this current study. He measured directly the percent of full sunlight and calculated the synecological values for the tree, shrub, and herbaceous canopies for five ecologically diverse forest types. He felt that a relationship did exist between direct light measurements and light requirements, calculated by the synecological coordinate method, but he was unable to make statistically valid comparisons due to great variations in the correlation coefficients.

METHODS

As part of a project to study the conversion of aspen to red pine in Itasca State Park, Lake Itasca, Minnesota, a series of study areas were established, and plots were laid out within these study areas. The study areas were four in number (see Figure 1) and covered forest types which were very closely related ecologically. The types included aspen (Populus tremuloides Michx.), birch (Betula papyrifera Marsh.), aspen with some birch, and red pine (Pinus resinosa Ait.). The birch and aspen areas consisted of 22 one-half acre plots which were fairly uniform, with a mature to overmature overstory. The aspen with birch area consisted of 23 one-half acre plots of mature aspen and birch trees, and was slightly more densely stocked than the other two areas. The red pine area was sampled with 15 one-half acre plots, since only this number of plots could be laid out in the chosen study area. The red pine area had the densest stocking and consisted of red pines well over 200 years old. All study areas selected had at least a moderate shrub layer, but the layer was quite heavy in all areas but the red pine area.

Using a Norwood Director photographic-type photometer, equipped with a hemispherical exposure lid, measurements were made at 20 stations on each one-half acre plot in all four of the areas. At each station a foot-candle reading of visible light was recorded for each of three heights: above the brush layer (below the overstory canopy), below the brush layer, and at the ground level (below the herbaceous layer). The twenty stations in each one-half acre plot were at predetermined, mechanically spaced intervals of about 7 feet in a "U" shaped pattern around the plot center. Care was taken not to disturb the vegetation from its natural condition or to allow the man reading the photometer to block the light stream or add excess light to the reading by reflections off of clothes, watches, etc. Whenever possible, the readings were taken at predetermined heights above the ground to eliminate bias in placement of the instrument, but sometimes obstacles such as tall shrub layer made this impossible. Quite frequently sunflecks or variations in light intensity occurred as the tree canopy moved in a wind or even a gentle breeze. When this happened, an average value for the range of variations observed over a few seconds was recorded as the value. The full sunlight intensity readings were taken in an open area, such as a road right of way, which was large enough to be unaffected by surrounding objects such as trees. These readings were taken about every one-half to three-fourths hour depending on the availability of open areas near the research plots. All light intensity measurements were taken between 10:00 and 14:00 Central Standard Time on cloudless or nearly cloudless days, in August and the first few days in September of 1966.

From the center of each stand, a variable plot cruise was made with a Bitterlick stick. This technique provided information on the basal area levels and percentage composition of the overstory for each species according to its basal area.

A list of all species present, regardless of their frequency, was made on each one-half acre plot by a complete examination of the entire plot's vegetation.

This raw data was then reduced into a simpler and more useable form. The light intensity measurements above brush, below brush, and at ground level were converted into a percent of full sunlight ("total site factor") value using the formula:

$$\frac{\text{light intensity in the plot}}{\text{light intensity in the full sunlight}} \text{ X } 100.$$

The data from the variable plot cruise were converted to square feet and percent of total basal area covered by each species. This was done for each plot and for each of the four study areas. Using the synecological light values suggested by Bakuzis and Hansen (1959), and the species presence list for each plot, it was possible to calculate a total synecological light value for all species on each plot. The community synecological light value was obtained by taking the average of the sums of the individual synecological light values for all species present in each plot. A community synecological value was also calculated for each of the study areas as an average of the community synecological values for each plot within the area.

Using this reduced data, correlation coefficients, using the standard linear regression equation, were calculated separately for the percent of full sunlight above brush, below brush, and at the ground level, in comparison with the community synecological light value for every plot in each area of the four study areas. Also, correlation coefficients were calculated separately for the mean percent of full sunlight above brush, below brush, and at ground level in comparison with the study area community synecological value for all four study areas.

The standard deviation of light intensity as a percent of full sunlight was calculated for the mean value of the percent of full sunlight above brush, below brush, and at ground level on each plot in each study area. Also, the standard deviation of the 20 foot-candle readings of light intensity in two randomly selected plots in each area, were calculated at the three different heights. The standard deviation equation: $s^2 = \frac{x^2 - (x)^2/n}{n - 1}$ was used in each case.

RESULTS

The percent of the full sunlight readings above brush, below brush, and at the ground level were fairly uniform. The highest percent of full sunlight value occurred in the aspen with birch area, above the brush, where the value was 19.75%, and the lowest percent of full sunlight value, 1.72%, occurred at ground level in the birch area. As can be seen in Tables II - V, there are similar percents of full sunlight values on all the four study areas with red pine tending to have slightly lower values than the other three types.

The range of community synecological values was also quite small. The highest was 3.17 in the aspen area, and the lowest was 2.76 in the red pine area. The other two values were intermediate, but closer to the higher than the lower value. Tables II to V give the community synecological light values for each plot and the average community synecological light value for each area. Table I contains a composite species presence list for all four study areas.

The standard deviations of mean percent of full sunlight above brush, below brush, and at ground level for each of the four study areas are of a moderate value compared to the mean. For example, above brush in the aspen with birch area, the "s" value is 8.923% and the mean is 19.57%.

The standard deviations of foot-candles on the two randomly selected plots in each of the four study areas was very great. For example, the first plot selected, above the brush, on the aspen with birch area, had a foot-candle value for the average of twenty readings of 1238 and a standard deviation of 1206 foot-candles. The complete list of standard deviations can be found in Table VI.

Tables II to V contain a brief summary of the results of the variable plot cruise. The greatest basal area, as would be expected, occurred in the red pine where the value was 157 square feet per acre. The basal area of the other three areas was somewhat similar with a range of 106 to 117 square feet per acre. The percentage composition of the overstory for each species, based on its basal area is also given in these tables.

Correlation coefficients of the percent of full sunlight, obtained separately, above brush, below brush, and at the ground level, in comparison with the community synecological light value for each of the plots in a study area were too low to be statistically valid. These values ranged from 0.405 for the percent of full sunlight above brush and the community synecological light value for the birch area, to -0.435 for the same level in the red pine area. Correlation coefficients of the mean percent of full sunlight calculated separately above brush, below brush, and at ground level, in comparison with the mean community synecological light value for the four types were somewhat better, but still not statistically significant. The values were 0.731, above brush, 0.792, below brush, and 0.381 at ground level. A complete summary of the findings is available in Table VI, and Figure 2 shows graphically the relationship of the mean percent of full sunlight at all three heights and the area community synecological value.

DISCUSSION

The high standard deviation in the foot-candle values shown by the randomly selected plots on each area seems to indicate that 20 light readings is not an adequate sample size to measure available light intensity in the mature forest stands measured. In many cases the standard deviation was in excess of the mean value of the twenty readings taken in the one-half acre plot. When the standard deviation was calculated for a whole area, using the mean light intensities at each of the three heights, the standard deviation was more moderate, showing less variation in the mean for an area than in the mean for a plot.

There seems to be a relationship between percent of full sunlight measured by a photometer and the synecological light value for all species present. The red pine area, which had the lowest community synecological light value, also had the lowest percent of full sunlight above the brush value. The other three study areas had very similar community synecological light values and also very similar light intensity levels. Since aspen and birch are very similar ecologically, and the stands compared were of similar age and basal area, it would be expected that they would have similar light intensity levels, which is true in this case. The community synecological light values were also quite similar, but the correlation coefficients were not strong enough to be statistically significant.

Another piece of evidence suggesting that a relationship does exist is the fact that much better correlation coefficients were obtained when the four areas were compared than when the plots within a study area were compared. This suggests that there is a relationship between the light intensity measured by the photometer and the community synecological light value which becomes stronger with a larger sample, as seen by the correlation coefficients between the areas and the correlation coefficients between plots within an area.

The results of this study can not be interpreted as proving or disproving the existence of a direct relationship between measured light intensity and community synecological light values. There is evidence within this study which suggests a relationship may exist. Since the standard deviations of light intensities within a half acre plot were excessively high, it is doubtful that a true, accurate estimation of light intensity within the forest was obtained by the method used in this study. The results of this study are open to question because of the light reading standard deviations.

In future work, I would suggest a larger number of light readings, approximately 40 to 60 in each half-acre plot be taken to obtain a more useful and accurate estimate of light intensity levels. It may be helpful to use fewer plots in each study area and have a larger ecological range of forest types represented in the study areas. This would allow more concentration of effort on a few plots, so that a more representative light intensity measure could be obtained. A larger number of ecologically diverse forest types would provide greater diversity for comparative study.

SUMMARY

A study of light intensity within four forest types in Itasca State Park, as it compares with synecological light values was carried out in the summer of 1966. The forest types were aspen, birch, aspen with some birch, and red pine which are all ecologically similar types.

Using a photometer, the percent of full sunlight values above the brush layer, below the brush layer, and at the ground level were measured.

The percent of full sunlight values ranged from 19.57% above the brush layer in an aspen with birch stand, to 1.72% at the ground level in the birch area. Using a list of species present an average synecological light requirement value was derived for all the species present. A variable plot cruise yielded information as to the basal area for the forest types. This same information was obtained for each of the 15 to 23 plots in each of the four forest types.

Correlation coefficients were calculated to measure the strength of the relationship between the measured percent of full sunlight above brush, below brush, and at ground level, and the average synecological light value. This was done for the plots within each area and also for the areas themselves. Too low correlation coefficients prevented valid statistical inferences as to

the relationship of synecological light values and percent of full sunlight readings. The author feels there is a relationship that exists between the two measurements of light which may be proven by a more refined experiment.

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Figure I

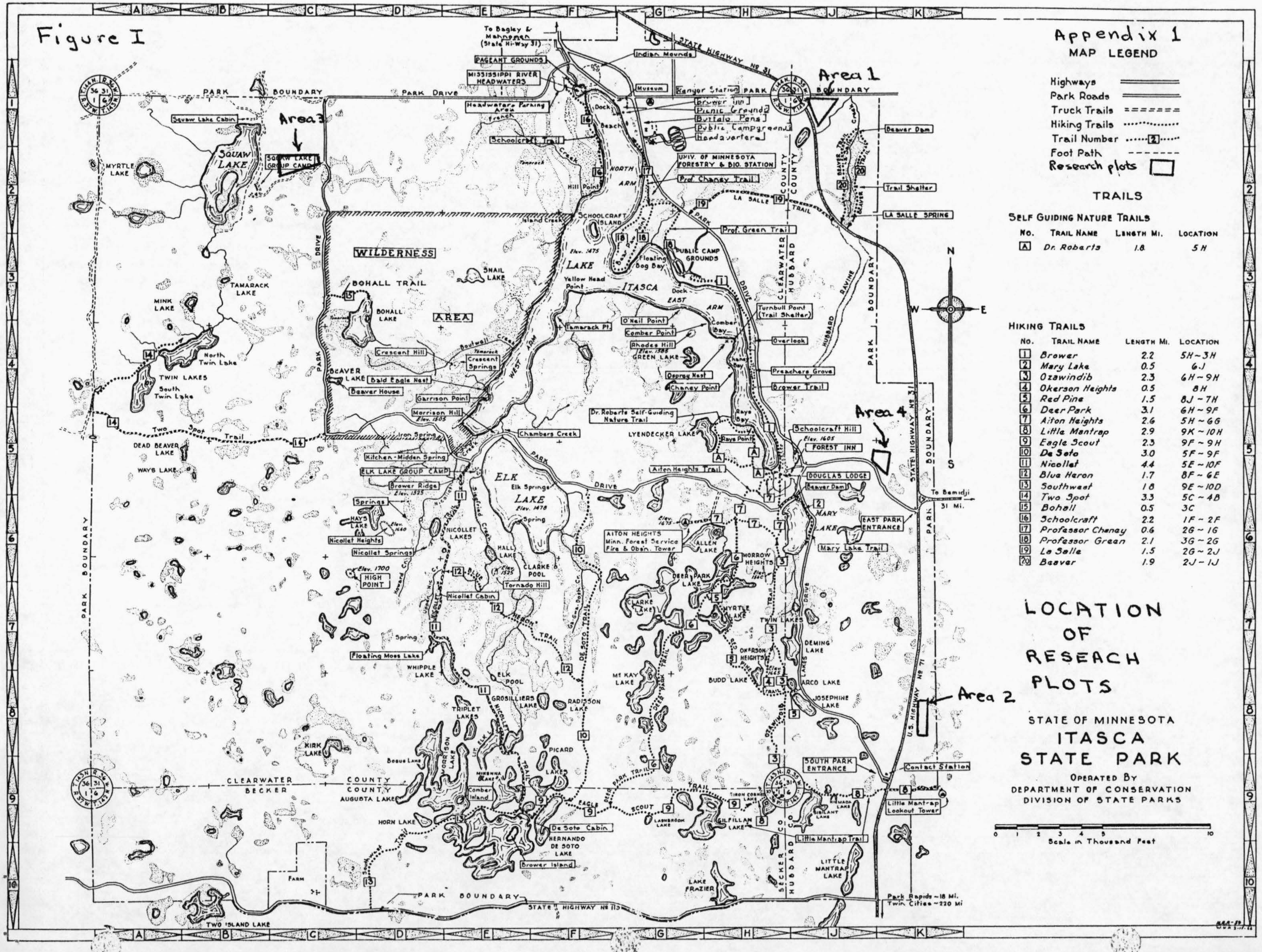
Appendix 1
MAP LEGEND
Highways
Park Roads
Truck Trails
Hiking Trails
Trail Number
Foot Path
Research plots
TRAILS
SELF GUIDING NATURE TRAILS
NO. TRAIL NAME LENGTH MI. LOCATION
A Dr. Roberts 1.8 5H
HIKING TRAILS
NO. TRAIL NAME LENGTH MI. LOCATION
1 Brower 2.2 5H ~ 3H
2 Mary Lake 0.5 6J
3 Ozawindib 2.3 6H ~ 9H
4 Okerson Heights 0.5 8H
5 Red Pine 1.5 8J ~ 7H
6 Deer Park 3.1 6H ~ 9F
7 Aiton Heights 2.6 5H ~ 6G
8 Little Mantrap 2.9 9K ~ 10H
9 Eagle Scout 2.3 9F ~ 9H
10 De Soto 3.0 5F ~ 9F
11 Nicollet 4.4 5E ~ 10F
12 Blue Heron 1.7 8F ~ 6E
13 Southwest 1.8 9E ~ 10D
14 Two Spot 3.3 5C ~ 4B
15 Bohall 0.5 3C
16 Schoolcraft 2.2 1F ~ 2F
17 Professor Chaney 0.6 2G ~ 1G
18 Professor Green 2.1 3G ~ 2G
19 La Salle 1.5 2G ~ 2J
20 Beaver 1.9 2J ~ 1J
LOCATION OF RESEARCH PLOTS
STATE OF MINNESOTA
ITASCA STATE PARK
OPERATED BY
DEPARTMENT OF CONSERVATION
DIVISION OF STATE PARKS
Scale in Thousand Feet
Area 1
Area 2
Area 3
Area 4
To Bagley & Mahnomen (State Hi-Way 31)
PAGEANT GROUNDS
MISSISSIPPI RIVER HEADWATERS
Indian Mounds
Museum
Ranger Station
Brower Inn
Picnic Grounds
Buffalo Pens
Public Campgrounds
Headquarters
UNIV. OF MINNESOTA FORESTRY & BIO. STATION
Prof. Chaney Trail
Headwaters Parking Area
Schoolcraft Trail
Squaw Lake Cabin
SQUAW LAKE GROUP CAMP
SQUAW LAKE
MYRTLE LAKE
PARK BOUNDARY
PARK DRIVE
STATE HIGHWAY No 31
WILDERNESS AREA
BOHALL TRAIL
BOHALL LAKE
SNAIL LAKE
TAMARACK LAKE
MINK LAKE
North Twin Lake
TWIN LAKES
South Twin Lake
DEAD BEAVER LAKE
WAYS LAKE
Two Spot Trail
SCHOOLCRAFT ISLAND
LAKE ITASCA
NORTH ARM
EAST ARM
WEST ARM
Prof. Green Trail
PUBLIC CAMP GROUNDS
Floating Bog Bay
Turnbull Point (Trail Shelter)
Tamarack Pt.
O'Neil Point
Comber Point
Rhodes Hill
GREEN LAKE
Osprey Nest
Chaney Point
Overlook
Preachers Grove
Brower Trail
Beaver Dam
Trail Shelter
LA SALLE SPRING
LA SALLE TRAIL
CLEARWATER COUNTY
HUBBARD COUNTY
Crescent Hill
Crescent Springs
Bald Eagle Nest
Beaver House
Garrison Point
Morrison Hill
Chambers Creek
Dr. Roberts Self-Guiding Nature Trail
LYENDECKER LAKE
Rays Point
Schoolcraft Hill
FOREST INN
Aiton Heights Trail
DOUGLAS LODGE
Beaver Dam
MARY LAKE
EAST PARK ENTRANCE
Mary Lake Trail
To Bemidji 31 Mi.
Kitchen-Midden Spring
ELK LAKE GROUP CAMP
Brower Ridge
Springs
HAYS LAKE
Nicollet Heights
Nicollet Springs
NICOLLET LAKES
ELK LAKE
HALL LAKE
CLARKE POOL
Tornado Hill
AITON HEIGHTS Minn. Forest Service Fire & Obs'n. Tower
ALLEN LAKE
MORROW HEIGHTS
HIGH POINT
Nicollet Cabin
DEER PARK LAKE
CLARKE LAKE
MYRTLE LAKE
TWIN LAKES
DEMING LAKE
Floating Moss Lake
WHIPPLE LAKE
ELK POOL
MC KAY LAKE
BUDD LAKE
ARCO LAKE
JOSEPHINE LAKE
TRIPLET LAKES
GROSILLIERS LAKE
RADISSON LAKE
PICARD LAKES
KIRK LAKE
Bogus Lake
MORRISON LAKE
Comber Island
AUGUSTA LAKE
HORN LAKE
De Soto Cabin
HERNANDO DE SOTO LAKE
Brower Island
SOUTH PARK ENTRANCE
Contact Station
Little Mantrap Lookout Tower
Little Mantrap Trail
LITTLE MANTRAP LAKE
LAKE FRAZIER
GILFILLAN LAKE
CLEARWATER COUNTY
BECKER COUNTY
U.S. HIGHWAY No 71
STATE HIGHWAY No 113
Park Rapids ~ 18 Mi.
Twin Cities ~ 220 Mi
FARM
TWO ISLAND LAKE

TABLE I: SPECIES PRESENCE LIST FOR FOUR FOREST COVER TYPES AND THE SYNECOLOGICAL VALUES[1] ASSIGNED TO THE INDIVIDUAL SPECIES

Trees	Synecological Light Value	Cover Types			
		Area 1 Aspen with Birch	Area 2 Birch	Area 3 Aspen	Area 4 Red pine
Abies balsamea (L.) Mill.	2				X
Acer rubrum L.	3	X	X	X	X
Acer saccharinum L.	4				X
Acer saccharum L.	1	X	X	X	X
Betula papyrifera Marsh.	5	X	X	X	X
Carpinus caroliniana Walt.	1	X		X	
Fraxinus nigra Marsh.	2	X			
Fraxinus pennsylvanica Marsh.	4	X	X	X	X
Ostrya virginiana (Mill.) Koch	1	X	X	X	X
Picea glauca (Moench) Voss	2	X		X	X
Pinus banksiana Lamb.	5		X		
Pinus resinosa Ait.	4			X	X
Pinus strobus L.	3	X			X
Populus balsamifera L.	3	X		X	
Populus grandidentata Michx.	3	X	X	X	X
Populus tremuloides Michx.	4	X	X	X	X
Prunus nigra Ait.	3		X	X	X

[1]as found in Bakuzis and Hansen (1959)

TABLE I: SPECIES PRESENCE LIST (Cont.)

Trees (cont.)	Synecological Light Value	Cover Types			
		Area 1	Area 2	Area 3	Area 4
Prunus serotina Ehrh.	3	X	X	X	
Quercus ellipsoidalis Hill	5	X			
Quercus macrocarpa Michx.	3	X	X	X	X
Quercus rubra L.	3	X	X	X	X
Tilia americana L.	1	X	X	X	X
Ulmus americana L.	2	X	X	X	X
Shrubs					
Acer spicatum Lam.	1				X
Alnus crispa (Ait.) Pursh	4	X	X	X	X
Alnus rugosa (Du Roi) Spreng.	4	X	X	X	X
Amelanchier spp.	4	X	X	X	X
Cornus alternifolia L.	1		X		
Cornus racemosa Lam.	3	X	X	X	X
Cornus rugosa Lam.	2	X	X	X	X
Cornus stolonifera Michx.	3	X	X		
Corylus americana Walt.	5	X	X		
Corylus cornuta Marsh.	3	X	X	X	X
Crataegus spp.	4	X		X	
Diervilla lonicera Mill.	3	X	X	X	X
Lonicera canadensis Marsh.	1				X
Lonicera hirsuta Eaton	3	X	X		
Prunus americana Marsh.	3	X			
Prunus pennsylvanica L. f.	5		X		X

TABLE I: SPECIES PRESENCE LIST (Cont.)

Shrubs (cont.)	Synecological Light Value	Cover Types			
		Area 1	Area 2	Area 3	Area 4
Prunus virginiana L.	4	X	X	X	X
Rhamnus alnifolia L'Her.	4	X			
Ribes cynosbati L.	2	X	X		
Rosa blanda Ait.	5	X	X	X	X
Salix humilis Marsh.	4	X	X	X	X
Sorbus americana Marsh.	1		X		
Symphoricarpos occidentalis Hook.	5		X	X	
Viburnum rafinesquianum Schult.	3	X	X	X	X
Viburnum trilobum Marsh.	3	X			
Xanthoxylum americanum Mill.	1	X			
Halfshrubs					
Rhus radicans L.	4	X	X	X	X
Rubus allegheniensis Porter	5		X	X	
Rubus idaeus L. var. strigosus (Michx.) Maxim.	3	X	X	X	X
Rubus pubescens Raf.	1	X	X	X	X
Vaccinium angustifolium Ait.	5	X	X	X	X
Vines					
Celastrus scandens L.	4	X			
Parthenocissus quinquefolia (L.) Planch.	3			X	X

TABLE I: SPECIES PRESENCE LIST (Cont.)

Ferns and Allies	Synecological Light Value	Cover Types			
		Area 1	Area 2	Area 3	Area 4
Athyrium filix-femina (L.) Roth.	1	X	X	X	X
Botrychium virginianum (L.) Sw.	1	X	X	X	X
Lycopodium complanatum L.	3		X		
Lycopodium obscurum L.	2				X
Onoclea sensibilis L.	3	X	X	X	
Osmunda claytoniana L.	2	X	X	X	X
Pteridium aquilinum (L.) Kuhn	4	X	X	X	X
Mosses and Lichens					
Mnium spp.	1	X	X	X	X
Forbs					
Achillea lanulosa Nutt.	2	X		X	
Actaea rubra (Ait.) Willd.	1	X	X	X	X
Agastache foeniculum (Prsh) Ktze.	4	X	X		X
Amphicarpa bracteate (L.) Fern.	3	X		X	
Anaphalis margaritacea (L.) Clarke.	5	X	X	X	
Apocynum androsaemifolium L.	5	X	X	X	X
Aquilegia canadensis L.	4		X		
Aralia nudicaulis L.	3	X	X	X	X
Aralia racemosa L.	1		X		
Asarum canadense L.	1	X			
Asclepias syriaca L.	5			X	
Aster lateriflorus (L.) Britt.	4		X	X	

TABLE I: SPECIES PRESENCE LIST (Cont.)

Forbs (cont.)	Synecological Light Value	Cover Types			
		Area 1	Area 2	Area 3	Area 4
Aster macrophyllus L.	3	X	X	X	X
Cicuta maculata L.	4	X	X	X	
Clintonia borealis (Ait.) Raf.	2	X	X	X	X
Cornus canadensis L.	2	X	X	X	X
Cypripedium reginae Walt.	2	X			
Fragaria virginiana Duchesne	4	X	X	X	X
Galium boreale L.	5	X	X	X	X
Galium labradoricum Wieg.	3		X		
Galium triflorum Michx.	1	X	X	X	X
Halenia deflexa (Smith) Griseb.	2				X
Helianthus laetiflorus Pers.	4		X		
Helianthus maximiliani Schrad.	5	X	X		
Hepatica americana (DC.) Ker	2	X	X	X	X
Impatiens capensis Meerb.	1		X		
Iris versicolor L.	5	X		X	
Lathyrus venosus Muhl.	5	X	X	X	X
Linnaea borealis L.	3				X
Lychnis alba Mill.	2				X
Lycopus uniflorus Michx.	2	X	X		
Lysimachia ciliata L.	4	X			
Maianthemum canadense Desf.	4	X	X	X	X
Monotropa uniflora L.	2			X	

TABLE I: SPECIES PRESENCE LIST (Cont.)

Forbs (cont.)	Synecological Light Value	Cover Types Area 1	Area 2	Area 3	Area 4
Osmorhiza claytoni (Michx.) Clarke	1	X	X	X	X
Pedicularis canadensis L.	5	X	X		
Petasites palmatus (Ait.) A. Gray	3	X	X	X	X
Petasites vitifolius Greene	2	X			
Polygonatum pubescens (Willd.) Pursh.	2		X		X
Pyrola asarifolia Michx.	2		X		
Pyrola elliptica Nutt.	3	X		X	X
Pyrola rotundifolia L.	3	X	X	X	X
Sanicula marilandica L.	3	X	X	X	X
Sium suave Walt.	4		X		
Smilacina racemosa (L.) Desf.	1	X	X		X
Smilax lasioneura Hook.	3	X			X
Streptopus roseus Michx.	1	X	X	X	X
Thalictrum dioicum L.	3	X	X	X	X
Trientalis borealis Raf.	1				X
Trifolium pratense L.	5	X			
Trillium cernuum L.	1	X	X		X
Trillium grandiflorum (Michx.) Salisb.	2				X
Uvularia grandiflora Smith	1	X	X	X	X
Uvularia sessilifolia L.	1	X	X	X	X

TABLE I: SPECIES PRESENCE LIST (Cont.)

Forbs (cont.)	Syneco-logical Light Value	Cover Types			
		Area 1	Area 2	Area 3	Area 4
Vicia americana Muhl.	3	X	X	X	X
Viola pubescens Ait.	3		X		X
Grasses and Sedges					
Bromus ciliatus L.	3	X	X	X	X

TABLE II: VARIABLE PLOT CRUISE DATA, PERCENT OF FULL SUNLIGHT ABOVE BRUSH, BELOW BRUSH, AND GROUND LEVEL, AND COMMUNITY SYNECOLOGICAL LIGHT VALUES

Area 1 Type: Aspen with Birch

Tree Species	Basal Area-Total square feet for trees counted	Percent of stand
Populus tremuloides Michx.	1280.5	43.12
Populus grandidentata Michx.	418.1	14.08
Betula papyrifera Marsh.	400.6	13.49
Quercus macrocarpa Michx.	382.8	12.89
Dead trees - all species	269.8	9.09
Quercus rubra L.	113.1	3.81
Populus balsamifera L.	43.5	1.46
Ostrya virginiana (Mill.) Koch	17.4	0.59
Prunus serotina Ehrh.	17.4	0.59
Tilia americana L.	17.4	0.59
Acer rubrum L.	8.7	0.29
Total for stand	2969.3	100.0

Average Basal Area per acre 117.0 (live) and 12.1 (dead)

TABLE II: (Cont.)

Area 1 Type: Aspen with Birch

Plot No.	Community Synecological Light Value	Percent of Full Sunlight Above Brush	Below Brush	Ground Level
A1	3.10	16.65	5.22	3.62
A2	3.06	27.71	9.77	1.57
B2	3.08	24.45	7.42	1.38
A3	3.12	17.42	2.55	0.98
B3	3.10	30.42	5.33	2.02
C3	3.16	39.92	6.30	2.35
D3	3.02	25.88	4.35	1.80
A4	2.85	17.52	5.03	2.15
B4	2.88	15.91	7.52	1.82
C4	2.93	27.45	4.51	2.14
D4	3.13	8.53	3.27	1.11
E4	3.18	17.38	3.26	1.05
A5	2.91	13.55	2.59	1.15
B5	2.93	14.64	1.83	1.86
C5	2.94	15.55	2.86	0.98
D5	3.04	34.80	4.21	1.38
E5	3.04	13.89	2.62	3.58
A6	2.79	15.74	3.38	1.12
B6	3.05	22.39	3.02	2.80
C6	2.96	14.27	3.85	2.67
A7	2.89	7.78	1.60	0.78
B7	2.93	18.76	2.45	1.71
C7	3.14	9.54	2.71	0.82
AVERAGE	3.01	19.57	4.16	1.78

TABLE III: VARIABLE PLOT CRUISE DATA, PERCENT OF FULL SUNLIGHT ABOVE BRUSH, BELOW BRUSH, AND GROUND LEVEL, AND COMMUNITY SYNECOLOGICAL LIGHT VALUES

Area 2 Type: Birch

Tree Species	Basal Area-Total square feet for trees counted	Percent of stand
Betula papyrifera Marsh.	1794.7	68.45
Populus tremuloides Michx.	479.1	18.27
Dead trees - all species	191.4	7.30
Quercus rubra L.	69.6	2.65
Populus grandidentata Michx.	34.8	1.33
Quercus macrocarpa Michx.	26.1	1.00
Populus balsamifera L.	17.4	0.66
Acer rubrum L.	8.7	0.33
Total for stand	2621.8	100.0

Average Basal Area per acre 110.5 (live) and 8.7 (dead)

TABLE III: (Cont.)

Area 2 Type: Birch

Plot No.	Community Synecological Light Value	Percent of Full Sunlight: Above Brush	Below Brush	Ground Level
A1	2.92	19.57	4.70	1.39
B2	2.98	24.53	4.56	1.30
A3	2.91	14.38	2.98	2.21
B3	3.00	8.42	8.54	4.17
A4	2.97	13.97	2.94	1.17
B4	2.97	11.37	8.52	1.28
A5	2.92	28.20	6.43	2.54
B5	2.97	13.26	5.03	2.15
A6	2.89	9.86	4.97	1.48
B6	2.83	14.00	4.00	2.11
A7	2.94	12.47	2.84	1.92
B7	3.00	11.39	4.03	1.77
C7	2.86	15.76	2.74	1.24
A8	2.79	12.00	3.47	1.63
C8	3.02	14.84	6.11	1.24
D8	2.90	11.90	2.81	1.28
A9	3.07	9.50	2.77	0.93
C9	2.97	6.26	2.10	1.24
D9	2.86	10.95	2.38	0.83
A10	3.17	36.61	10.91	3.06
B10	3.26	19.74	2.86	1.74
C10	2.87	7.03	2.44	1.14
AVERAGE	2.96	14.82	4.46	1.72

TABLE IV: VARIABLE PLOT CRUISE DATA, PERCENT OF FULL SUNLIGHT ABOVE BRUSH, BELOW BRUSH, AND GROUND LEVEL, AND COMMUNITY SYNECOLOGICAL LIGHT VALUES

Area 3 Type: Aspen

Tree Species	Basal Area-Total square feet for trees counted	Percent of stand
Populus tremuloides Michx.	1768.7	68.61
Dead trees - all species	252.3	9.79
Populus grandidentata Michx.	191.5	7.43
Betula papyrifera Marsh.	182.8	7.09
Quercus rubra L.	104.4	4.05
Quercus macrocarpa Michx.	34.8	1.35
Acer rubrum L.	17.4	0.67
Fraxinus nigra Marsh.	8.7	0.34
Ostrya virginiana (Mill.) Koch	8.7	0.34
Prunus serotina Ehrh.	8.7	0.34
Total for stand	2578.0	100.0

Average Basal Area per acre 105.7 (live) and 11.5 (dead)

TABLE IV: (Cont.)

Area 3 Type: Aspen

Plot No.	Community Synecological Light Value	Percent of Full Sunlight Above Brush	Below Brush	Ground Level
A1	3.11	8.81	4.26	2.58
B1	3.07	16.35	10.63	2.47
A2	3.16	17.83	9.91	7.43
B2	3.14	22.26	9.07	4.65
C2	3.08	17.70	6.26	3.39
A3	3.04	8.90	3.48	2.19
B3	3.18	21.73	9.86	3.06
C3	3.18	19.60	7.33	2.87
D3	3.30	23.37	11.73	2.84
A4	3.11	10.48	3.00	1.70
B4	3.32	25.29	9.45	5.29
C4	3.18	14.53	3.67	1.09
D4	3.27	12.45	11.64	7.02
E4	3.28	23.65	3.62	1.45
F4	3.25	16.92	5.09	2.00
A5	3.20	9.71	2.23	0.91
B5	3.02	6.35	3.35	0.89
C5	3.20	12.26	2.79	1.06
D5	3.28	8.77	7.52	1.97
F5	3.18	18.12	1.80	1.62
G5	3.18	16.67	7.42	7.14
C6	3.09	20.86	12.69	1.45
AVERAGE	3.17	16.03	6.67	2.96

TABLE V: VARIABLE PLOT CRUISE DATA, PERCENT OF FULL SUNLIGHT ABOVE BRUSH, BELOW BRUSH, AND GROUND LEVEL, AND COMMUNITY SYNECOLOGICAL LIGHT VALUES

Area 4 Type: Red pine

Tree Species	Basal Area-Total square feet for trees counted	Percent of stand
Pinus resinosa Ait.	1315.4	54.33
Acer rubrum L.	270.1	11.16
Populus tremuloides Michx.	261.4	10.78
Pinus strobus L.	243.6	10.06
Populus grandidentata Michx.	113.2	4.68
Betula papyrifera Marsh.	95.7	3.95
Dead trees - all species	60.9	2.52
Quercus rubra L.	52.2	2.16
Ostrya virginiana (Mill.) Koch	8.7	0.36
Total for stand	2421.2	100.0

Average Basal Area per acre 157.3 (live) and 4.1 (dead)

TABLE V: (Cont.)

Area 4 Type: Red pine

Plot No.	Community Synecological Light Value	Percent of Full Sunlight Above Brush	Below Brush	Ground Level
A1	2.72	10.53	2.88	1.82
B1	2.63	18.86	4.53	3.60
C1	2.74	7.04	5.70	2.84
A2	2.72	9.62	6.60	3.48
B2	2.93	7.92	4.50	2.19
C2	2.68	10.33	4.27	2.44
A3	2.78	10.69	3.65	1.85
B3	2.79	11.00	4.25	1.96
C3	2.86	4.73	4.50	1.90
D3	2.72	8.42	4.62	2.62
C4	2.69	11.58	5.23	4.92
E4	2.85	11.50	1.77	1.71
C5	2.68	3.69	2.48	1.08
D5	2.75	3.46	2.85	1.17
E5	2.77	8.33	3.92	0.98
AVERAGE	2.76	9.18	4.12	2.30

TABLE VI: STATISTICAL SUMMARY

Plot Correlation Coefficients

Description	Area 1	Area 2	Area 3	Area 4
Percent of Full Sunlight Above Brush and Community Synecological Value for each plot	0.289	0.405	0.227	-0.435
Percent of Full Sunlight Below Brush and Community Synecological Value for each plot	0.159	0.348	0.107	-0.246
Percent of Full Sunlight Ground Level and Community Synecological Value for each plot	0.074	0.230	0.120	-0.469

Area Correlation Coefficients

Description	Correlation Coefficient
Mean Percent of Full Sunlight Above Brush and Mean Community Synecological Value for each area	0.731
Mean Percent of Full Sunlight Below Brush and Mean Community Synecological Value for each area	0.792
Mean Percent of Full Sunlight Ground Level and Mean Community Synecological Value for each area	0.381

TABLE VI: STATISTICAL SUMMARY (Cont.)

Means of Percent Full Sunlight and Their Standard Deviations

Description	Area 1	Area 2	Area 3	Area 4
Above Brush				
$\bar{x}$ (mean)	19.57	14.82	16.03	9.18
s (standard deviation)	8.293	7.199	5.632	3.816
Below Brush				
$\bar{x}$	4.16	4.46	6.67	4.12
s	2.035	2.346	3.505	1.261
Ground Level				
$\bar{x}$	1.78	1.72	2.96	2.30
s	0.818	0.774	2.057	1.067

Mean Foot-candles of Sunlight and Their Standard Deviations

Description	Area 1	Area 2	Area 3	Area 4
Randomly Selected Plot No. 1				
Above Brush				
$\bar{x}$ (mean)	1238	862	932	1075
s (standard deviation)	1206	1038	359	1522
Below Brush				
$\bar{x}$	162	327	606	258
s	203	637	1090	216
Ground Level				
$\bar{x}$	113	140	141	205
s	110	144	231	193
Randomly Selected Plot No. 2				
Above Brush				
$\bar{x}$	966	690	822	404
s	1133	335	521	379
Below Brush				
$\bar{x}$	121	163	768	222
s	97	117	1547	144
Ground Level				
$\bar{x}$	123	74	463	126
s	231	55	1451	52

Figure II: The Mean Percent of Full Sunlight Above Brush, Below Brush, and at Ground Level and the Community Synecological Value